
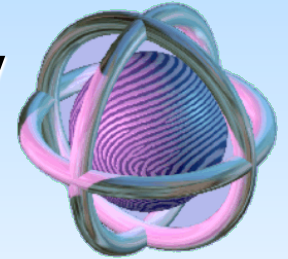


**Raffaele Cappelli, Davide Maltoni**

**BioLab - Biometric System Laboratory**  
University of Bologna - ITALY 

<http://biolab.csr.unibo.it>

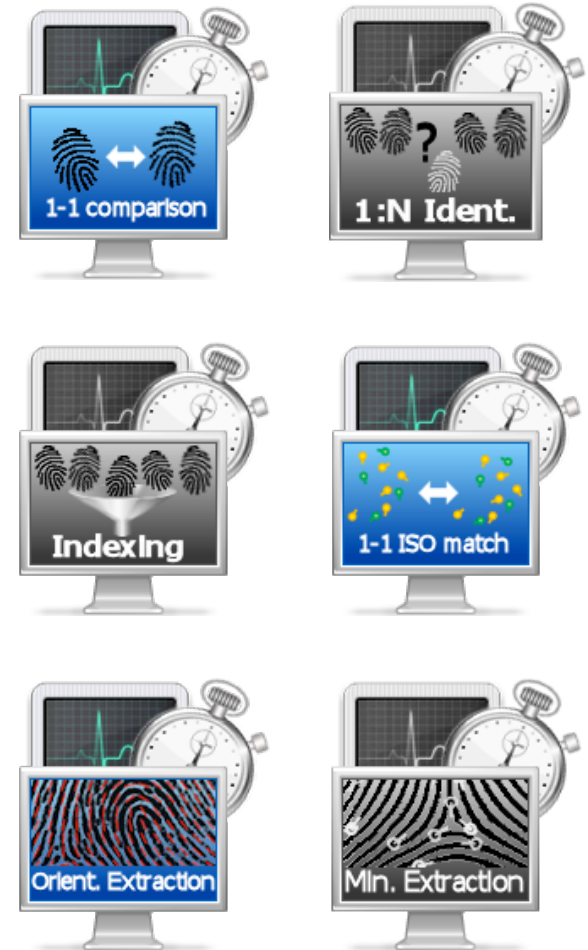


# **FVC-onGoing**

On-line Evaluation of  
Fingerprint Recognition Algorithms

# Outline

- FVC: Fingerprint Verification Competitions
  - Background
  - What's new in FVC-onGoing
- How FVC-onGoing works
  - Architecture of the system
  - An example of evaluation
- Benchmark areas and benchmarks
  - Fingerprint verification
  - ISO template matching
  - Fingerprint orientation Extraction
- The next steps
  - New benchmark areas planned



# Fingerprint Verification Competitions

- FVC: Technology Evaluations of Fingerprint Verification Algorithms
- Since 1999, when we started organizing FVC2000:
  - Four competitions: FVC2000, FVC2002, FVC2004, FVC2006
  - A total of 179 algorithms were evaluated
  - A total of 16 databases were collected and made available



# FVC-onGoing

- Web-based automatic evaluation of fingerprint recognition algorithms
  - Participants can be: companies, academic research groups, or independent developers
  - Algorithms are tested on sequestered datasets and results are reported using well-known performance indicators and metrics
- Fully automated:
  - 1.The system automatically tests the algorithm submitted by a participant
  - 2.The participant sees the results in its “private area”
  - 3.Then the participant may decide to publish the results in the public section of the FVC-onGoing web site
- Main aim:
  - Track the advances in fingerprint recognition technologies, through continuously updated independent testing and reporting of performances on given benchmarks





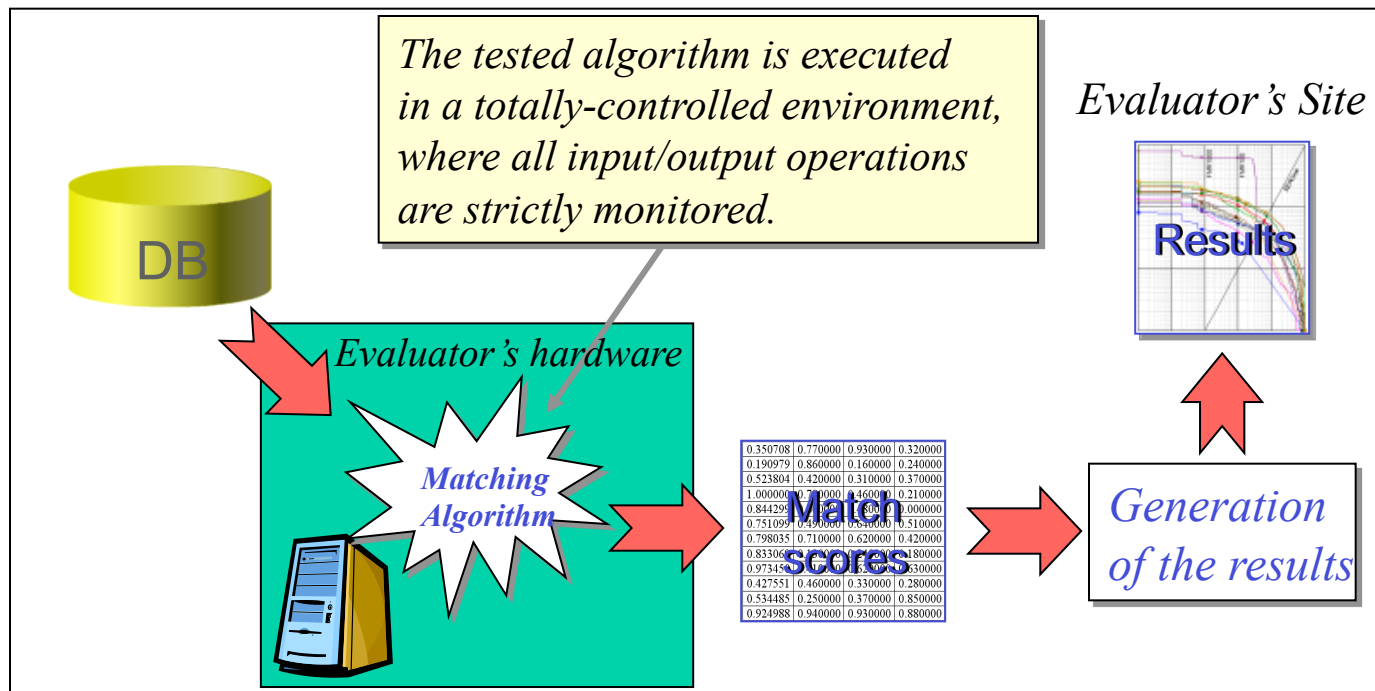
# What's new in FVC-onGoing

- Previous FVC initiatives were organized as “competitions”
  - Specific calls and Fixed time frames
- FVC-onGoing is:
  - An “on going competition” always open to new participants
    - Datasets will remain sequestered
  - An evolving online repository of benchmarks, evaluation metrics and results
    - However the benchmark datasets will not evolve over time; in case new datasets will be added in the future, they will form a different benchmark (or a new version of an existing one)
- Not only limited to fingerprint verification algorithms:
  - Ad hoc benchmarks for testing specific modules of fingerprint verification systems are being made available:
    - Orientation Image Extraction (already available)
    - Fingerprint indexing
    - Minutiae Extraction

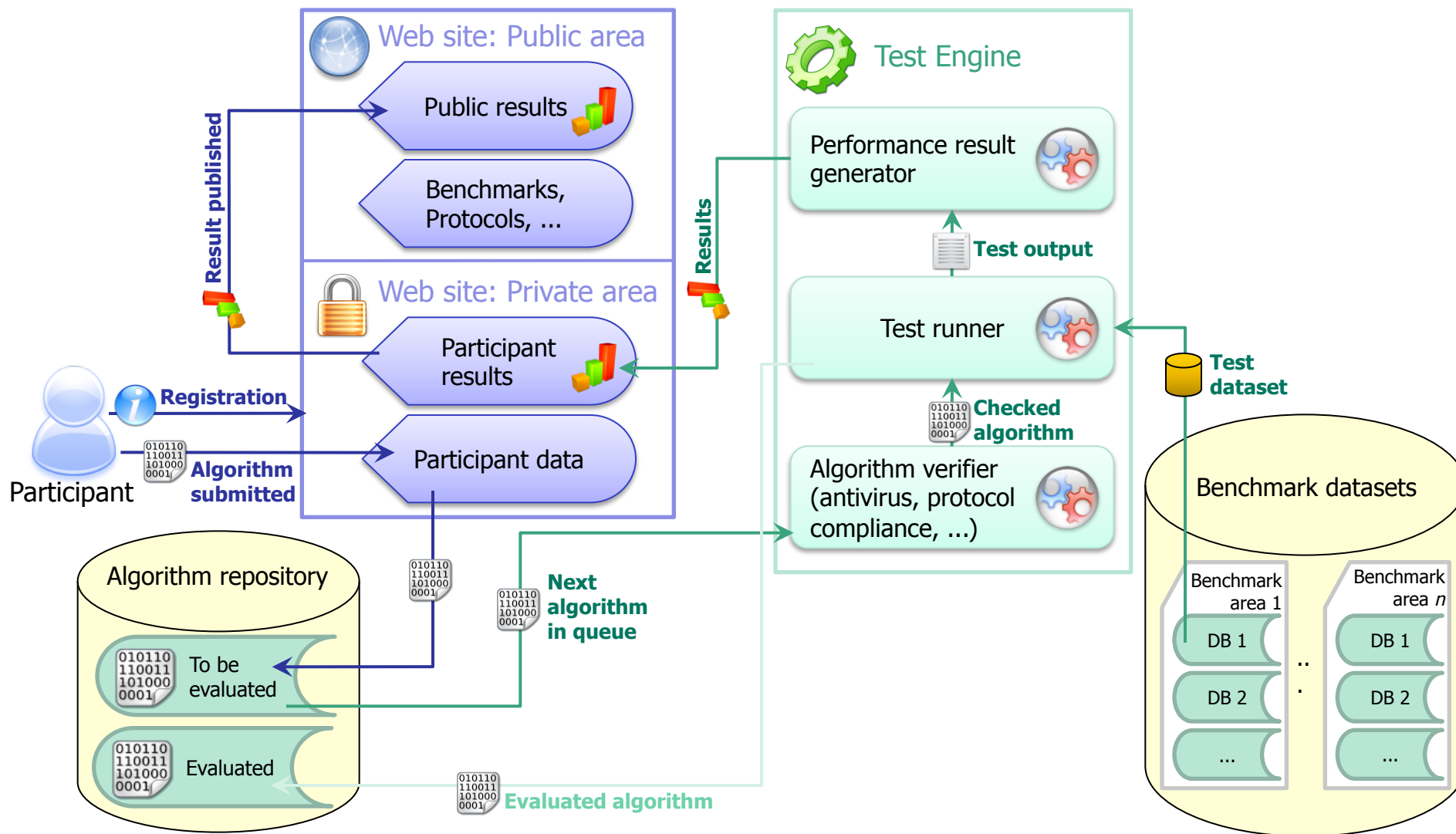


# FVC-onGoing: Testing procedure

- As in previous FVCs, the testing procedure is Strongly Supervised
  - Protocol: *binary executable programs* compliant to a given input/output protocol are tested on the evaluator's hardware
  - Results: generated by the evaluator from the matching scores obtained during the test



# FVC-onGoing: Workflow



# An example...

**FVC onGoing**

Public area

- Home
- Background
- Benchmarks
- Register
- Published Results

Participant area

- Login
- Upload
- Pending Algorithms
- Tested Algorithms
- Download
- Past editions

Past editions

- FVC2006
- FVC2004
- FVC2002
- FVC2000

**FVC-onGoing: on-line evaluation of fingerprint recognition algorithms**

FVC-onGoing is a web-based automated evaluation system for fingerprint recognition algorithms. Tests are carried out on a set of sequestered datasets and results are reported on-line by using well known performance indicators and metrics.

The aim is to track the advances in fingerprint recognition technologies, through continuously updated independent testing and reporting of performances on given benchmarks. The algorithms are evaluated using strongly supervised approaches to maximize trustworthiness.

FVC-onGoing is the evolution of FVC: the international Fingerprint Verification Competitions organized in 2000, 2002, 2004, and 2006.

**Submission and Publication policy**

Interested companies, academic research groups, and independent developers can register for an account on this web site and submit an algorithm to a given benchmark. The system will test the algorithm and the participant will see the results in its private area. Then the participant may decide to publish the results of its algorithm on the FVC-onGoing public result section, where they will be visible to any other web user.

**Current status of the project**

The system is currently under a beta-testing phase: only invited beta testers can submit algorithms.

The official start of FVC-onGoing is scheduled in June 2009, in conjunction with ICB2009.

**Organization**

- Biometric System Laboratory team (University of Bologna, Italy)
  - D. Maio
  - D. Maltoni
  - R. Cappelli
  - A. Franco
  - M. Ferrara
  - L. Palamkin






FVC-onGoing: on-line evaluation of fingerprint recognition algorithms

# Benchmark areas and benchmarks




- FVC-onGoing benchmarks are grouped into Benchmark Areas
- All the benchmarks of a given benchmark area:
  - Address the same (sub)problem
  - Share the same evaluation protocol
- Each benchmark is based on a sequestered dataset that will not evolve over time
  - In case new datasets will be added in the future, they will form a different benchmark (or a new version of an existing one).
  - Only results obtained on the same benchmark are comparable.
  - A participant may submit more algorithms to the same benchmark
    - But there is a minimum break (e.g. one month) between consecutive submissions
- Currently available benchmark areas:
  - FV: fingerprint verification using proprietary templates
  - FMISO: fingerprint matching using ISO/IEC 19794-2 templates
  - FOE: fingerprint orientation extraction (orientation image)



# Currently available benchmarks





| Area   | Benchmark      | Description   |
|--|----------------|---|
|  <b>FV</b><br>Fingerprint Verification              | FV-TEST        | A simple dataset useful to test algorithm compliancy with the testing protocol  |
|  | FV-STD-1.0     | Fingerprint images acquired in operational conditions using high-quality optical scanners   |
|  | FV-HARD-1.0    | Difficult cases (noisy images, distorted impressions, etc.): more challenging   |
|  <b>FMISO</b><br>Fingerprint ISO Template Matching | FMISO-TEST     | A simple dataset useful to test algorithm compliancy with the testing protocol  |
|  | FMISO-STD-1.0  | Fingerprint images acquired in operational conditions using high-quality optical scanners   |
|  | FMISO-HARD-1.0 | Difficult cases (noisy images, distorted impressions, etc.): more challenging   |
|  <b>FOE</b><br>Fingerprint Orientation Extraction | FOE-TEST       | A simple dataset useful to test algorithm compliancy with the testing protocol  |
|  | FOE-STD-1.0    | Orientation extraction benchmark on fingerprints with orientation ground-truth manually labeled using an ad-hoc software tool. Good-quality and bad-quality datasets. |

# Current status

| Registered Participants  |                          | 127 |
|--|--------------------------|-----|
|   | Academic Research Groups | 21  |
|   | Companies                | 46  |
|  | Independent Developers   | 60  |



From July 2009  
to February 2010

| Algorithm Evaluated   |                                   | 388 |
|---|-----------------------------------|-----|
|    | Fingerprint Verification          | 260 |
|    | Fingerprint ISO Template Matching | 128 |
| Results Published   |                                   | 20  |
|   | Fingerprint Verification          | 11  |
|  | Fingerprint ISO Template Matching | 9   |



# Protocols and results: on the web site

Benchmark protocols,  
Published results,  
Performance  
indicators,  
Graphs,  
...

The screenshot displays the FVC-onGoing website interface. At the top, the user is logged in as 'Raffaele Cappelli'. The left sidebar contains navigation links for 'Public area' (Home, Background, Benchmarks, Register, Published Results, Statistics) and 'Participant area' (Logout, Upload, Pending Algorithms, Tested Algorithms, Download, Past editions: FVC2006, FVC2004, FVC2002, FVC2000). The main content area is titled 'Benchmarks' and provides an overview of the benchmarks. It lists three benchmark areas: 'Fingerprint Verification', 'Fingerprint Matching (ISO)', and 'Fingerprint Orientation Extraction'. Each area includes a description of the benchmark and a table of available benchmarks.

| Benchmark Area  | Benchmarks                                    |
|---|---|
| <b>Fingerprint Verification</b><br>This benchmark area contains fingerprint verification benchmarks. Fingerprint verification consists in comparing two fingerprints to determine whether they are impressions of the same finger or not (one-to-one comparisons). Algorithms submitted to these benchmarks are required to enroll fingerprints into proprietary or standard templates and to compare such templates to produce a similarity score. Read more...  | FV-STD-1.0<br>FV-TEST<br>FV-HARD-1.0          |
| <b>Fingerprint Matching (ISO)</b><br>This benchmark area contains fingerprint matching benchmarks using a standard minutiae-based template format [ISO/IEC 19794-2 (2005)]. Algorithms submitted to these benchmarks are required to compare ISO fingerprint templates to determine whether they are impressions of the same finger or not (one-to-one comparisons). No fingerprint enrollment (feature extraction) is required, only the minutiae matching algorithms are evaluated by these benchmarks. Read more...  | FMISO-STD-1.0<br>FMISO-TEST<br>FMISO-HARD-1.0 |
| <b>Fingerprint Orientation Extraction</b><br>The estimation of local fingerprint orientations is a fundamental step in fingerprint analysis and recognition (e.g., it is a prerequisite for image enhancement). This benchmark area contains benchmarks for local orientation extraction algorithms. Algorithms submitted to these benchmarks are required to extract local orientations from fingerprint images and to save them into a specific format. The extracted orientations are compared to the ground-truth in order to assess the algorithm accuracy. Read more... | FOE-TEST<br>FOE-STD-1.0                       |

<http://biolab.csr.unibo.it/FVConGoing>










FVC-onGoing: on-line evaluation of fingerprint recognition algorithms







# FV: Fingerprint Verification

- Benchmark FV-STD-1.0:






| Published on | Benchmark  | Participant        | Type    | Algorithm | Version | EER ▲  | FMR1000 | FMR10000 | Show details  |
|--------------|------------|--------------------|---------|-----------|---------|--------|---------|----------|---|
| 01/03/2010   | FV-STD-1.0 | Green Bit S.p.A    | Company | GBFRSW    | 1.2.0.0 | 0,194% | 0,274%  | 0,519%   |  |
| 24/02/2010   | FV-STD-1.0 | AA Technology Ltd. | Company | EMB9200   | 2.1     | 0,216% | 0,296%  | 0,440%   |  |
| 25/11/2009   | FV-STD-1.0 | Green Bit S.p.A    | Company | GBFRSW    | 1.0.0.0 | 0,261% | 0,364%  | 0,487%   |  |
| 20/07/2009   | FV-STD-1.0 | Neurotechnology    | Company | MM_FV     | 3.0     | 0,281% | 0,386%  | 0,581%   |  |
| 31/08/2009   | FV-STD-1.0 | UnionCommunity     | Company | Triple_M  | 1.0     | 0,665% | 1,389%  | 2,403%   |  |
| 15/07/2009   | FV-STD-1.0 | Secuest Inc.       | Company | STAR      | 1.0     | 1,265% | 2,504%  | 4,026%   |  |
| 24/06/2009   | FV-STD-1.0 | jFinger Co., Ltd.  | Company | JF_FV     | V1.21a  | 1,618% | 2,872%  | 4,545%   |  |

- Benchmark FV-HARD-1.0:





| Published on | Benchmark   | Participant        | Type    | Algorithm | Version | EER ▲  | FMR1000 | FMR10000 | Show details  |
|--------------|-------------|--------------------|---------|-----------|---------|--------|---------|----------|---|
| 24/02/2010   | FV-HARD-1.0 | AA Technology Ltd. | Company | EMB9200   | 2.1     | 0,824% | 1,558%  | 2,376%   |  |
| 01/03/2010   | FV-HARD-1.0 | Green Bit S.p.A    | Company | GBFRSW    | 1.2.0.0 | 0,827% | 1,667%  | 2,619%   |  |
| 25/11/2009   | FV-HARD-1.0 | Green Bit S.p.A    | Company | GBFRSW    | 1.0.0.0 | 1,046% | 2,210%  | 3,152%   |  |
| 20/07/2009   | FV-HARD-1.0 | Neurotechnology    | Company | MM_FV     | 3.0     | 1,528% | 3,043%  | 4,079%   |  |

# FMISO: Fingerprint ISO Template Matching

- Benchmark FMISO-STD-1.0:

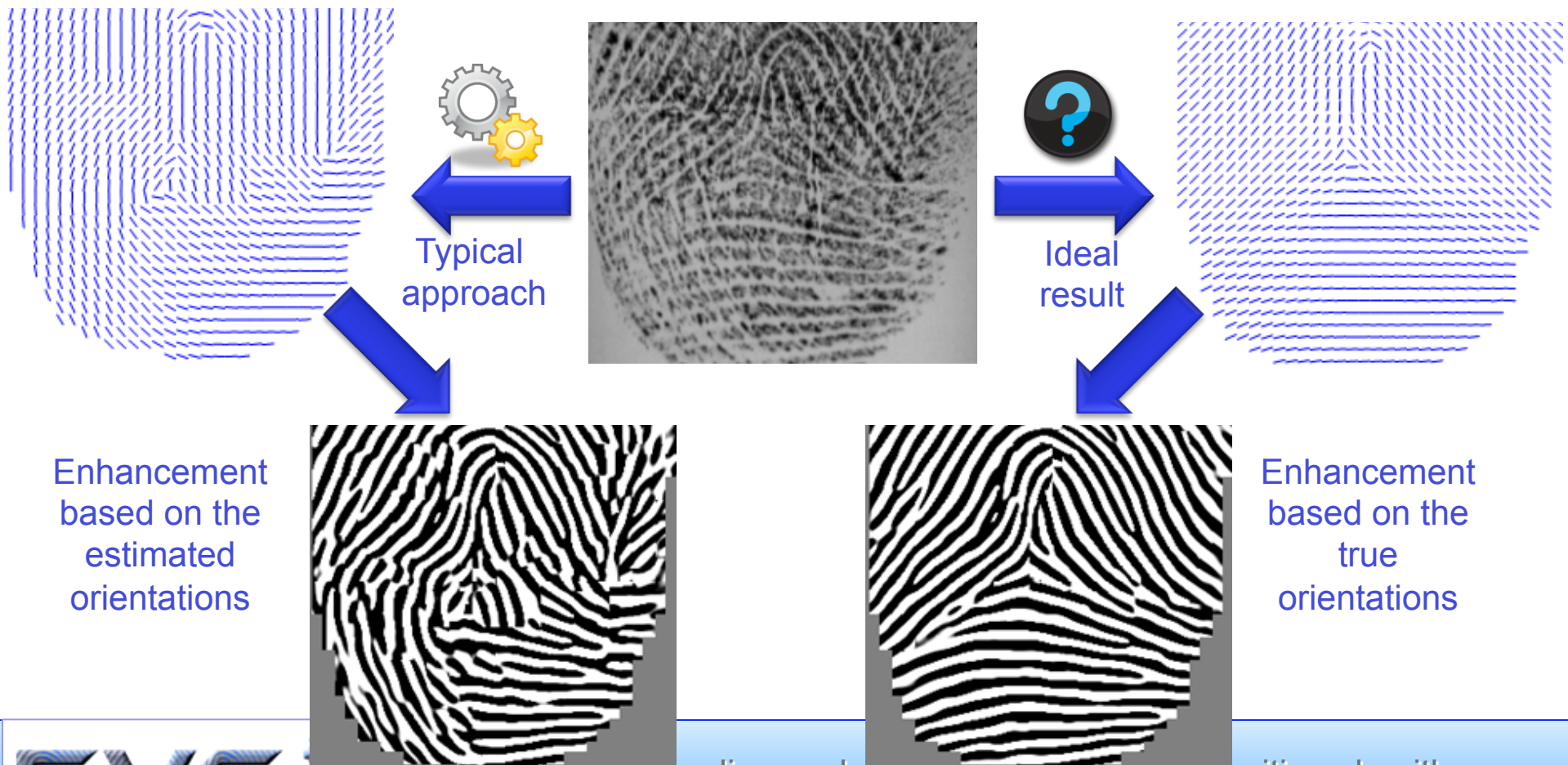
| Published on | Benchmark     | Participant                         | Type    | Algorithm    | Version | EER ▲  | FMR1000 | FMR10000 | Show details  |
|--------------|---------------|-------------------------------------|---------|--------------|---------|--------|---------|----------|---|
| 12/10/2009   | FMISO-STD-1.0 | Tiger IT Bangladesh                 | Company | Tiger ISO    | 0.1     | 0,317% | 0,447%  | 0,866%   |  |
| 09/09/2009   | FMISO-STD-1.0 | UnionCommunity                      | Company | Triple_M_ISO | 1.0     | 0,405% | 0,610%  | 1,064%   |  |
| 26/02/2010   | FMISO-STD-1.0 | AA Technology Ltd.                  | Company | EMB9200      | 2.1     | 0,432% | 0,570%  | 0,880%   |  |
| 26/09/2009   | FMISO-STD-1.0 | APRO TECHNOLOGY (BANGKOK) CO., LTD. | Company | APF_FMISO    | 1.1     | 0,582% | 0,801%  | 1,057%   |  |
| 20/07/2009   | FMISO-STD-1.0 | Neurotechnology                     | Company | MM_FMISO     | 3.0     | 0,598% | 0,801%  | 1,234%   |  |

- Benchmark FMISO-HARD-1.0:

| Published on | Benchmark      | Participant                         | Type    | Algorithm    | Version | EER ▲  | FMR1000 | FMR10000 | Show details  |
|--------------|----------------|-------------------------------------|---------|--------------|---------|--------|---------|----------|---|
| 26/02/2010   | FMISO-HARD-1.0 | AA Technology Ltd.                  | Company | EMB9200      | 2.1     | 1,700% | 3,002%  | 4,545%   |  |
| 09/02/2010   | FMISO-HARD-1.0 | UnionCommunity                      | Company | Triple_M_ISO | v1.1    | 1,927% | 3,908%  | 5,280%   |  |
| 20/07/2009   | FMISO-HARD-1.0 | Neurotechnology                     | Company | MM_FMISO     | 3.0     | 2,430% | 4,607%  | 6,139%   |  |
| 26/09/2009   | FMISO-HARD-1.0 | APRO TECHNOLOGY (BANGKOK) CO., LTD. | Company | APF_FMISO    | 1.1     | 2,552% | 4,581%  | 5,963%   |  |

# New Benchmark: Fingerprint Orientation Extraction

- Challenge: Estimation of local orientations in low-quality images
  - A fundamental step in fingerprint analysis and recognition



# Evaluating Fingerprint Orientation Extraction

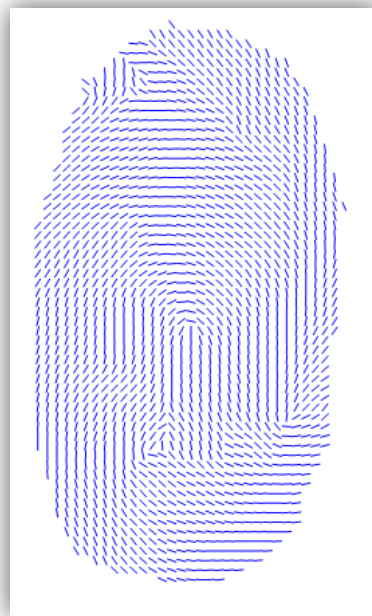
- How the benchmark works:
  - Participants' algorithms are required to extract local orientations from fingerprint images and to save them into a specific format.
  - The extracted orientations are compared to the **ground-truth** in order to assess the algorithm accuracy.



Fingerprint



Ground truth



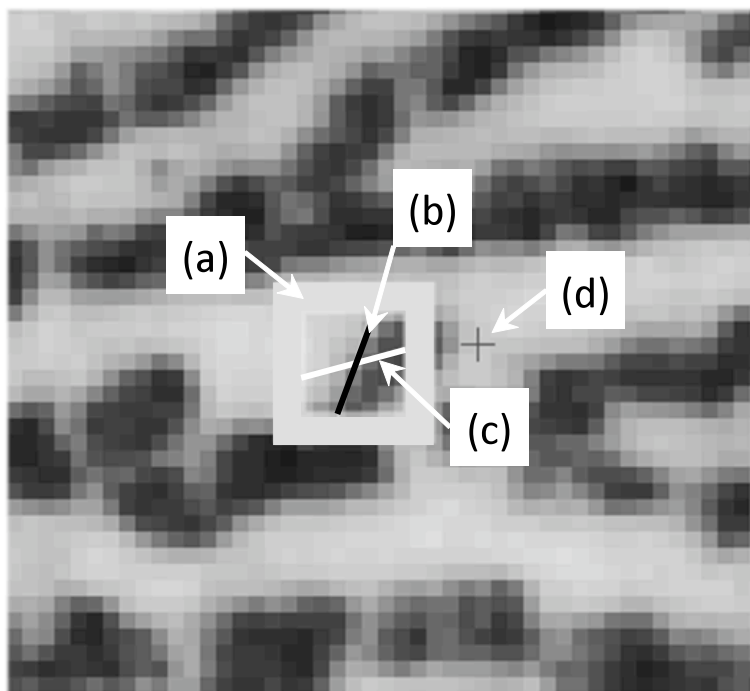
Extracted



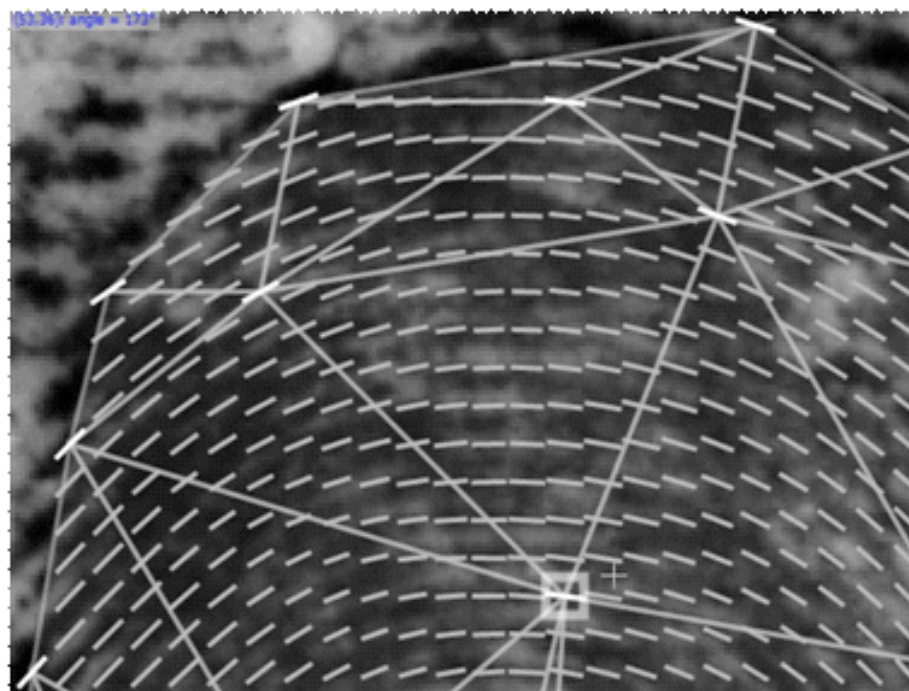
Errors



# Software tool for orientation ground truth markup

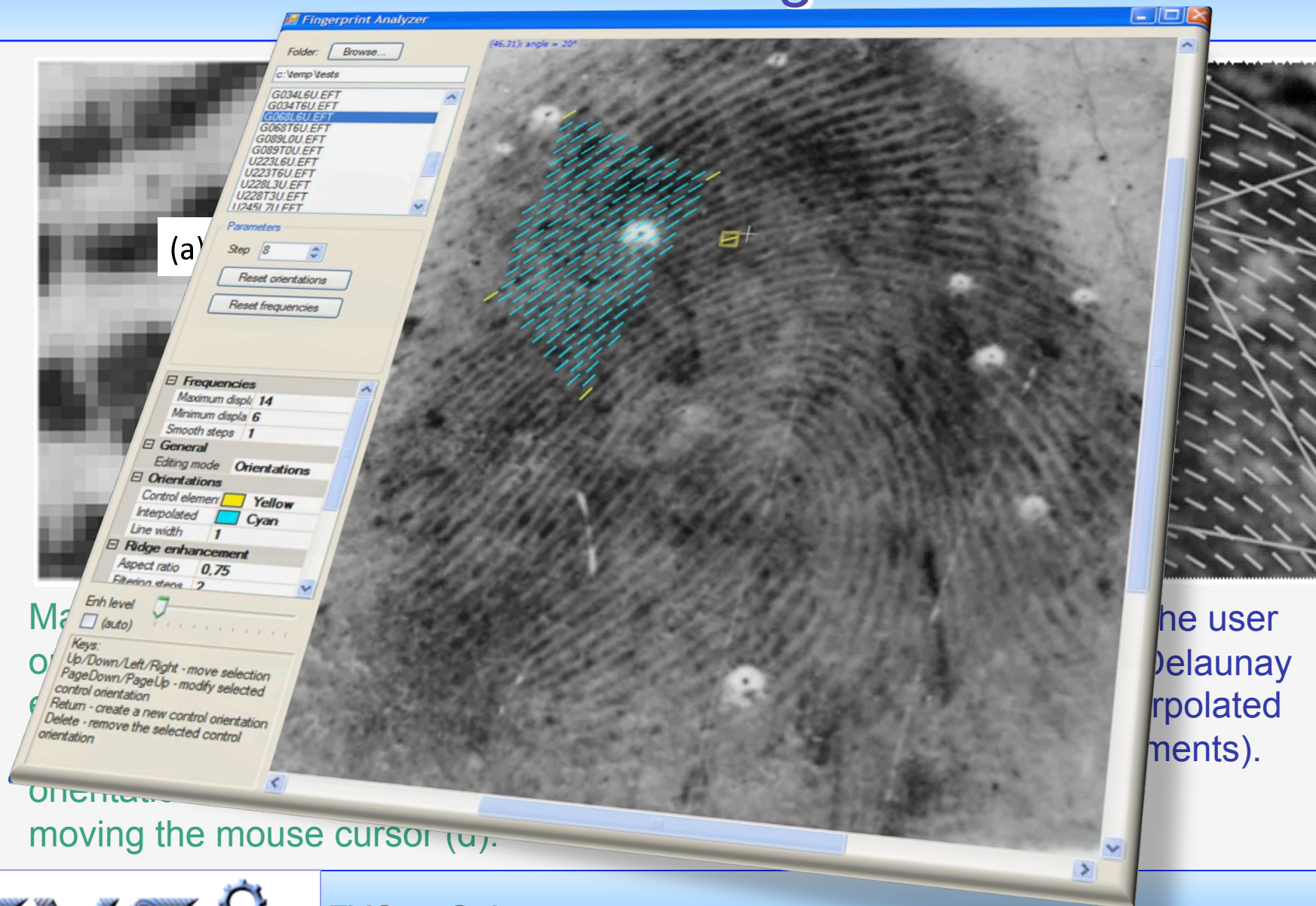


Manual adjustment of a single local orientation element: (a) the selected element, (b) the initial orientation proposed by the software, (c) the orientation selected by the user moving the mouse cursor (d).



Local estimations made by the user (white segments), with the Delaunay triangulation and all the interpolated local orientations (grey segments).

# Software tool for orientation ground truth markup



the user  
Delaunay  
interpolated  
elements).

# FOE: Datasets and Performance Indicators

- Datasets:

- The benchmarks consists of 2 datasets: a good quality dataset and a bad quality dataset.
- The challenge is to obtain a good orientation extraction accuracy on the bad quality dataset without losing too much accuracy on the good quality dataset.
  - To reduce noise on low quality fingerprints, some approaches tend to oversmooth the orientation image and this could compromise accuracy on good quality fingerprints.

- Performance indicators:

- $\text{AvgErr}_{\text{BQ}}$  (Average Error on the Bad Quality Dataset)
- $\text{AvgErr}_{\text{GQ}}$  (Average Error on the Good Quality Dataset)
- Average orientation extraction time, Maximum amount of memory allocated
- Orientation deviation histogram (over all the orientation elements)
- Average error histogram (over all the fingerprints)

# FOE: Datasets and Performance Indicators

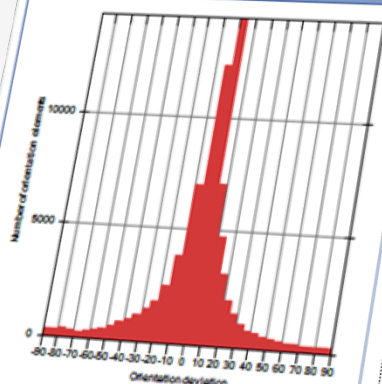
- Datasets:
  - The benchmarks consists of 2 datasets: a good quality dataset and a bad quality dataset.

| Accuracy indicators  |                      |
|----------------------|----------------------|
| AvgErr <sub>BQ</sub> | AvgErr <sub>GQ</sub> |
| 22,91°               | 6,12°                |

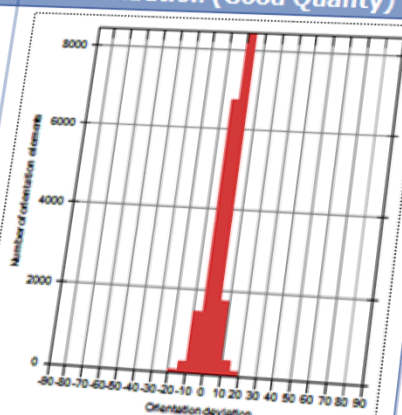
| Efficiency and memory indicators |                      |
|----------------------------------|----------------------|
| Avg Extraction Time              | Max Memory Allocated |
| 77 ms                            | 42604 KBytes         |

## Graphs

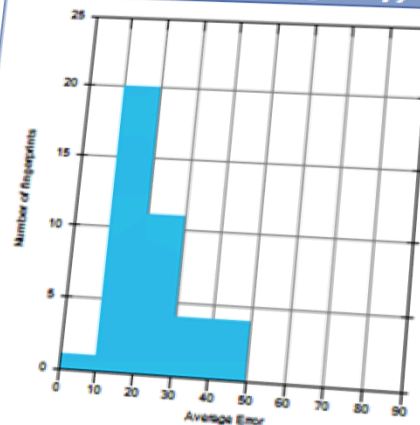
Orientation deviation distribution (Bad Quality)



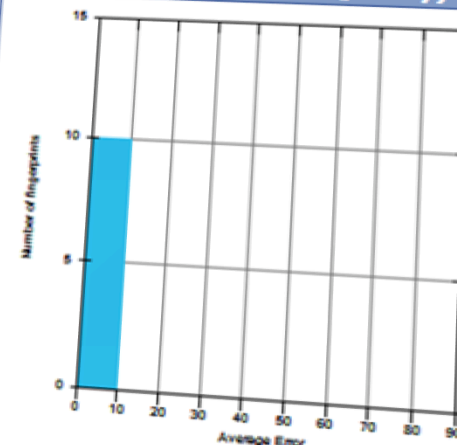
Orientation deviation distribution (Good Quality)



Average error distribution (Bad Quality)



Average error distribution (Good Quality)





# FOE: Participant's toolkit and samples

- Source code: C and C# skeletons are available.
  - Perform all the necessary I/O (including loading image and foreground, saving the orientation image, ...).
- Sample datasets
- Sample algorithm (Gradient-based) and Test runner tool
- Software viewer to display:
  - Fingerprints,
  - Ground truth,
  - Orientations extracted by an algorithm,
  - Orientation differences (errors)



# FOE: Participant's toolkit and samples

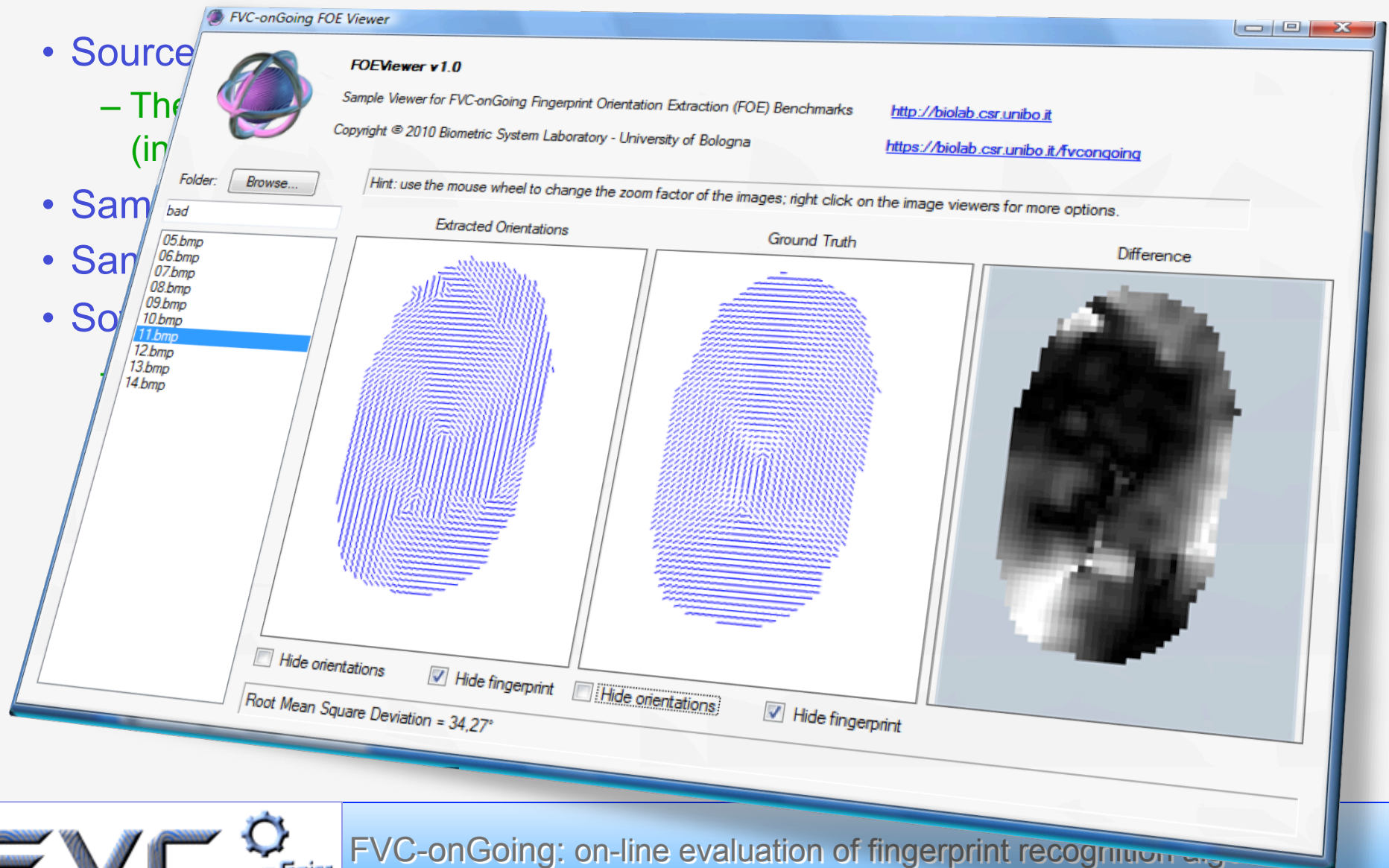
- Source

– The  
(in

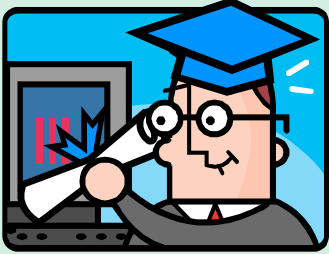

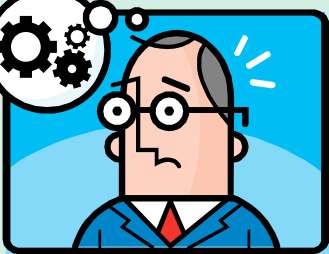
- Sam

- Sam

- So



# FVC-onGoing: for Whom?

| Who   | Why   |
|---|---|
|  <p>Researcher<br/>Reviewer</p>        | <ul style="list-style-type: none"><li>• New algorithms can be easily compared to the state-of-the-art.</li><li>• Benchmarks not only for the whole recognition problem, but also for sub-problems.</li></ul>  |
|  <p>Vendor<br/>Developer</p>          | <ul style="list-style-type: none"><li>• FVC-onGoing is an evolving online repository of evaluation metrics and results.</li><li>• Participants can see the results before publishing.</li><li>• The competition is always open: new algorithms and new versions can be submitted at any time.</li></ul> |
|  <p>End user<br/>Sys. Integrator</p> | <ul style="list-style-type: none"><li>• At any time, end users and system integrators may ask potential providers to assess their performance on one or more benchmarks.</li><li>• An evolving snapshot of the fingerprint recognition technology.</li></ul>  |



## The next steps

- New benchmark areas planned

- Fingerprint Indexing
- Fingerprint Identification (1:N)
- Minutiae extraction accuracy



- New benchmarks with synthetic datasets

- Large datasets for Fingerprint Orientation Extraction (orientation ground-truth can be automatically generated by SFinGe)
- Datasets for Minutiae Extraction Accuracy (minutiae ground-truth automatically generated by SFinGe)

### **SFinGe (the Italian for Sphinx, pron. *sphin-je*)**

A software able to synthetically (randomly) generate large databases of realistic fingerprint images with ground truth data (minutiae, local orientations, ...)



# Links



- FVC-onGoing web site:

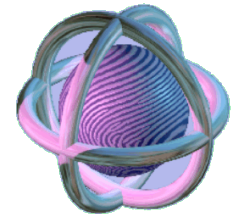
🌐 <http://biolab.csr.unibo.it/FVConGoing>

🌐 ...or Google “fvc on going” and press “I’m Feeling Lucky”


- Biometric System Laboratory web site:

🌐 <http://biolab.csr.unibo.it>

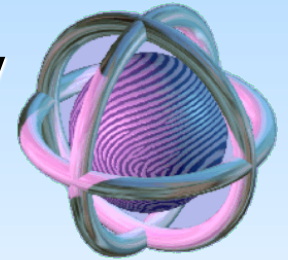
🌐 ...or Google “biometric system laboratory” and press “I’m Feeling Lucky”



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BioLab - Biometric System Laboratory  
University of Bologna - ITALY 

<http://biolab.csr.unibo.it>



# Thank you !





# Benchmark Area Fingerprint Verification (FV)

- Benchmarks:

- FV-TEST: A simple dataset useful to test algorithm compliancy with the testing protocol.
  - Results cannot be published.
- FV-STD-1.0: Fingerprint images acquired in operational conditions using high-quality optical scanners.
  - Results should reflect the expected accuracy in large-scale fingerprint-based applications.
- FV-HARD-1.0: Contains a relevant number of difficult cases (noisy images, distorted impressions, etc.) that makes fingerprint verification more challenging.
  - Results do not necessarily reflect the expected accuracy in real applications.



| Benchmark   | Scanner Type | Resolution | Minimum Image Size | Maximum Image Size | Genuine Attempts | Impostor Attempts |
|-------------|--------------|------------|--------------------|--------------------|------------------|-------------------|
| FV-TEST     | Optical      | 500 dpi    | 440x500            | 440x500            | 280              | 45                |
| FV-STD-1.0  | Optical      | 500 dpi    | 440x500            | 440x500            | 27720            | 87990             |
| FV-HARD-1.0 | Optical      | 500 dpi    | 260x374            | 448x500            | 19320            | 20850             |

# Fingerprint Verification (FV): Protocol

- From the FVC-onGoing web site:

Each participant is required to submit, for each algorithm, **two** executables in the form of Win32 console applications.

- Both executables will take the input from command-line arguments and will append the output to a text file.

1. The first executable (**enroll.exe**) enrolls a fingerprint image and produces a template file; the command-line syntax is:  
`enroll.exe <imagefile> <templatefile> <outputfile>`

where:

|              |  |
|--------------|--|
| imagefile    | the input image pathname   |
| templatefile | the output template pathname   |
| outputfile   | the output text-file, where a log string (of the form imagefile templatefile result) must be appended; result is "OK" if the enrollment can be performed or "FAIL" if the input image cannot be processed by the algorithm |

2. The second executable (**match.exe**) matches two fingerprint templates and produces a similarity score; the command-line syntax is:  
`match.exe <templatefile1> <templatefile2> <outputfile>`

where:

|               |  |
|---------------|--|
| templatefile1 | the first input template pathname  |
| templatefile2 | the second input template pathname   |
| outputfile    | the output text-file, where a log string (of the form templatefile1 templatefile2 result similarity) must be appended; result is "OK" if the matching can be performed or "FAIL" if the matching cannot be executed by the algorithm; similarity is a floating point value ranging from 0 to 1 which indicates the similarity between the two templates: 0 means no similarity, 1 maximum similarity |

- Both executables have to operate only on the explicitly-given inputs, without exploiting any learning technique or template consolidation/update based on previous enrolls/matches.
- C and C# language skeletons for enroll.exe and match.exe are available in the [download](#) page to reduce the participants implementation efforts. These source files perform all the necessary I/O (including image loading).



# Benchmark Area Fingerprint Matching ISO (FMISO)

- Benchmarks:

- FMISO-TEST: A simple dataset useful to test algorithm compliancy with the testing protocol
  - Results obtained on this benchmark cannot be published.
- FMISO-STD-1.0: ISO templates created from fingerprint images acquired in operational conditions using high-quality optical scanners.
  - Results should reflect the expected accuracy in large-scale fingerprint-based applications.
- FMISO-HARD-1.0: Contains a relevant number of difficult cases (noisy images, distorted impressions, etc.).
  - Results do not necessarily reflect the expected accuracy in a real applications.



| Benchmark      | Scanner Type | Resolution | Minimum Template Size | Maximum Template Size | Genuine Attempts | Impostor Attempts |
|----------------|--------------|------------|-----------------------|-----------------------|------------------|-------------------|
| FMISO-TEST     | Optical      | 500 dpi    | 440x500               | 440x500               | 280              | 45                |
| FMISO-STD-1.0  | Optical      | 500 dpi    | 440x500               | 440x500               | 27720            | 87990             |
| FMISO-HARD-1.0 | Optical      | 500 dpi    | 260x374               | 448x500               | 19320            | 20850             |

# Fingerprint Matching ISO (FMISO): Protocol

- From the FVC-onGoing web site:

## Protocol

Each participant is required to submit, for each algorithm, an executable in the form of Win32 console application.

- The executable (**match.exe**) will take the input from command-line arguments and will append the output to a text file. It matches two ISO templates and produces a similarity score; the command-line syntax is:

```
match.exe <ISOtemplatefile1> <ISOtemplatefile2> <outputfile>
```

where:

|                  |  |
|------------------|--|
| ISOtemplatefile1 | the first input ISO template pathname  |
| ISOtemplatefile2 | the second input ISO template pathname   |
| outputfile       | the output text-file, where a log string (of the form ISOtemplatefile1 ISOtemplatefile2 result similarity) must be appended; result is "OK" if the matching can be performed or "FAIL" if the matching cannot be executed by the algorithm; similarity is a floating point value ranging from 0 to 1 which indicates the similarity between the two templates: 0 means no similarity, 1 maximum similarity |

- The executable has to operate only on the explicitly-given inputs**, without exploiting any learning technique or template consolidation/update based on previous enrolls/matches.
- C and C# language skeletons** for match.exe are available in the [download](#) page to reduce the participants implementation efforts. These source files perform all the necessary I/O (including ISO template loading).